Copyright

by

Alison Fayre Mills

2011

The Thesis Committee for Alison Fayre Mills
Certifies that this is the approved version of the following thesis:

Entry-lane Capacity Analysis of Roundabouts in Texas Using VISSIM, SIDRA, and the Highway Capacity Manual

APPROVED BY
SUPERVISING COMMITTEE:

Supervisor: ______________________________
Randy B. Machemehl

____
Jennifer C. Duthie

Entry-lane Capacity Analysis of Roundabouts in Texas Using VISSIM, SIDRA, and the Highway Capacity Manual

by

Alison Fayre Mills, B.S.C.E

Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Masters of Science in Engineering

The University of Texas at Austin

August 2011

Dedication

My family

Acknowledgements

I would like to thank my advisor Dr. Randy Machemehl and Dr. Jennifer Duthie for invaluable guidance and assistance during my work on this project. I thank researchers with Texas A&M Kingsville for helping me to collect the data used in this work. Thank you to Kim Pham for her hard work this summer that allowed me ample time to finish this thesis. I also would like to acknowledge the Texas Department of Transportation for providing funding for this research.

Abstract

Entry-lane Capacity Analysis of Roundabouts in Texas Using VISSIM, SIDRA, and the Highway Capacity Manual

Alison Fayre Mills, MSE

The University of Texas at Austin, 2011

Supervisor: Randy B. Machemehl

Road safety and traffic congestion are two of the critical issues facing the transportation profession today. As a means to promote safety and efficiency at United States intersections modern roundabouts are becoming more and more common. Over the last ten years, roundabouts implementation methodologies have been developed using data collected at U.S. roundabouts. These methodologies were first published in National Cooperative Highway Report 572: Roundabouts in the United States and more recently in the second edition of the national roundabout guidelines. This work attempts to validate the use of these methodologies for roundabouts in the state of Texas and also enhance guidelines for evaluating roundabout operations by exploring the effects of exiting flow, origin-destination patterns, and mean speed on roundabout entry-lane capacity. Capacity results from VISSIM are compared to the Highway Capacity Manual entry-lane capacity curve and results from SIDRA.

Table of Contents

List of Tables

List of Figures

Chapter 1 – Introduction

1.1 MOTIVATION FOR THE WORK

Road safety and traffic congestion are two of the critical issues facing the transportation profession today. Although the United States was once the international leader in safety, Australia, Germany, Great Britain, and Sweden now out rank the U.S. in terms of safety (TRB, 2009). Metropolitan areas are plagued with traffic congestion as private vehicles are used for 87% of all passenger trips (TRB, 2009). The state of Texas has not been exempt from these issues. TxDOT and local jurisdictions face the challenge of finding and creating innovative solutions to deal with safety and congestion. Roundabouts provide significant safety benefits and travel savings if they are strategically placed and well designed.

As a means to promote safety and efficiency at United States intersections modern roundabouts are becoming more and more common. The national guidelines published in 2000 were brought about by early roundabout design and construction followed by a series of state guidelines for roundabout analysis, design, and implementation. However, the information in the first edition of the guidelines was largely based on roundabouts outside the U.S. and research indicated that the methodologies did not accurately represent the performance of U.S. roundabouts. Over the last ten years, methodologies have been developed using data collected at U.S. roundabouts and published first in National Cooperative Highway Report Project 572: Roundabouts in the United States and most recently in the second edition of the national roundabout guidelines (National Cooperative Highway Report Project 672: Roundabouts: An Informational Guide Second Edition).

1.2 PROJECT OVERVIEW

There are currently few roundabouts in the state of Texas. The Texas Department of Transportation commissioned a project beginning in September 2009 to create effective roundabout guidelines for Texas so that roundabouts might become more common in the state as a means to address safety and efficiency. These guidelines are intended to be a compilation of existing guidelines, recent research finds, and validation. These components are critical to providing sound and enhanced safety and operations methodologies as well as design and implementation guidelines for roundabouts.

The project is divided into ten tasks. Task 1 involves a systematic and comprehensive review of the state of the practice in roundabout design, development, and use in the U.S. The primary objective of the review will be to support the development of state guidelines for planning, analyzing, and designing roundabouts in Texas. The findings from the literature review and survey will be synthesized to guide further research.

Task 2 is development of a safety assessment methodology for roundabouts based on the relatively recent safety performance research focusing on roundabouts in the United States. Primary components include crash prediction models and parameters and methodology for calculating the anticipated crash reduction due to converting an existing intersection to a roundabout.

The objective of Task 3 is to recommend methodologies to predict roundabout capacity, delay, and queue lengths. Traffic analysis guidelines are recommended by reviewing and assessing existing methods and recent research. This task is intended to provide valuable perspective for balancing model complexity with meaningful and timely output.

A roundabout's geometry plays a significant role in effectiveness and safety. Task 4 develops geometric design guidelines and principles providing the foundation for effective and consistent roundabout designs in Texas. The guidelines developed in this task will be incorporated into the final Texas Roundabout Guide holistically and clearly presenting the critical design principles, dimensions, and key considerations useful for creating consistent and effective single- and multilane roundabout designs applicable to urban and rural environments as well as different functional road classes.

Task 5 involves collecting data necessary to calibrate the traffic simulation model created in Task 6. Geometric, speed, and traffic volume data are collected at roundabout sites across Texas. These sites were chosen with the help of PMC and other TxDOT personnel.

Task 6 means to confirm the design criteria developed in previous tasks produces reasonable results from an operational and safety perspective. Microsimulation results are used to enhance the guidelines for evaluating roundabout operations. VISSIM and SIDRA are used to evaluate the performance of roundabouts at the intersection level.

Task 7 begins the implementation component of the project with the development of a quantitative procedure for comparing the benefits of roundabout design to traditional intersection form. This will allow TxDOT to identify intersections where roundabouts will provide superior service to motorized and non-motorized modes. The analysis procedure will be in the form of a spreadsheet tool.

Task 8 integrates the individual components of the planning process established in the previous tasks into a consistent and systematic screening procedure. The workbook that will come out of this task will represent the relationships between geometric design, safety, traffic operations, and total benefits.

A pilot roundabout design and evaluation workshop for Texas DOT engineers will be conducted for Task 9. Texas DOT engineers will be introduced to the design and operations guidelines developed in this project, the benefit/cost evaluation tool, and the implementation framework.

Task 10 is the final report and recommendations that document the research project activities, methodologies, assumptions, resources, and final recommendations. The framework developed in Task 8 may be included in this final report as it's own distinct section.

Tasks 1 through 6 have been completed at this time and the remaining tasks will be completed by the end of August 2011.

The table below offers brief descriptions of the outcomes of each task.

Tasks Number	Outcomes of each task (to be included or described in Tech Memos)
1	Synthesized current roundabout design guidelines, practices, and recent research findings
2	Initial methodology for assessing safety
3	Initial methodology for conducting traffic operations analysis
4	Initial guidelines and principles for geometric design
5	Data and procedure for calibrating microsimulation model
6	Microsimulation model used to validate and refine initial methodologies Guidelines for effectively using analytical software programs; to be incorporated into final guidance document
7	Benefit/Cost evaluation framework to compare roundabouts with alternative intersection forms
8	Workbook documenting implementation framework for roundabout planning and design
9	Pilot workshop materials
10	Final Roundabout Guidelines incorporating final safety, operations, geometric design techniques, guidance for using software programs, evaluation framework and implementation considerations. Final Report

Table 1: Outcomes of project tasks

This thesis focuses on task six of the project involving using microsimulation models to validate and refine methodologies developed in previous tasks.

1.3 OBJECTIVES

The objective of this study is to use microsimulation results from VISSIM and the relatively common roundabout analysis software SIDRA to enhance the current guidelines for evaluating roundabout operations. VISSIM is used to conduct the analysis of capacity and results are compared to capacity values found using SIDRA and the current Highway Capacity Manual (HCM) entry lane capacity curve. This study uses two roundabouts located in Texas for analysis in VISSIM and SIDRA. One is located in Southlake, Texas and then other is a considerably smaller roundabout located in San Antonio, Texas. The primary contribution of this work is to provide new insight into estimating entry-lane capacity. The effects of exiting flow, origin-destination patterns, and mean speed on roundabout capacity will be evaluated separately in hopes of improving current guidelines for evaluating roundabout operations by offering recommendations for how the current methodology should be expanded. This work offers a secondary contribution by showing that VISSIM can reasonably validated for roundabouts and offering a methodology for calibration and validation. Literature review in these areas will be explained throughout the work.

Assuming that VISSIM provides the most behaviorally consistent approach to capacity analysis, researchers are also asking the questions: Can the HCM predict roundabout capacity? Can SIDRA?

The structure of this work is as follows. Chapter 2 and 3 discuss the characteristics of a modern roundabout and the specific roundabout sites used for analysis in this study. Chapter 4 describes the software and procedures used during analysis. Chapter 5 offers a general discussion of roundabout entry lane capacity as well as detailed discussion of what is currently known about the effects of exiting flow, origin-destination patterns, and mean speed on capacity. Chapter 6 discusses the analysis results and Chapter 7 summarizes this study findings.

Chapter 2 - Roundabouts

2.1 WHAT IS A ROUNDABOUT?

A roundabout, a type of circular intersection, is characterized by counterclockwise traffic movement around a central island. Traffic entering the roundabout must yield to traffic that is already circulating around this island. Figure 1 from the 2010 Highway Capacity Manual depicts a modern roundabout with its key characteristics identified.

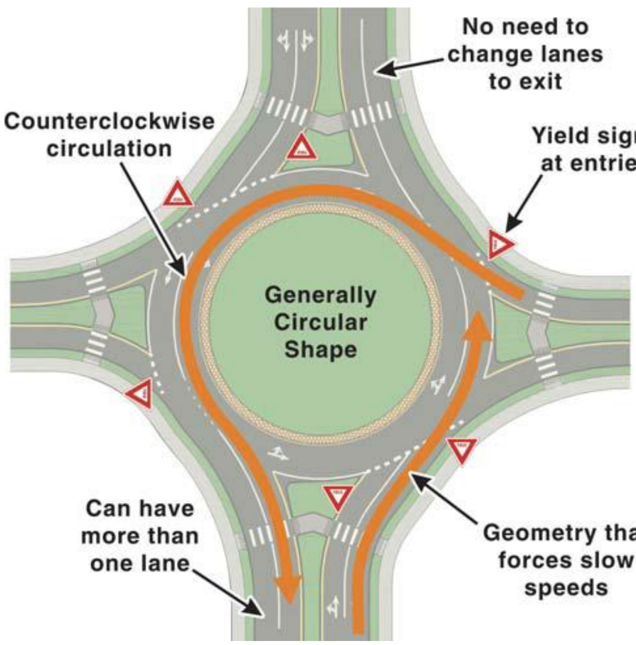


Figure 1: Key Roundabout Characteristics (Source: 2010 HCM)

Table 2 contains information regarding the key features of a modern roundabout.

Feature	Description
Central island	The central island is the raised area in the center of a roundabout around which traffic circulates. The central island does not necessarily need to be circular in shape. In the case of mini-roundabouts the central island is traversable.
Splitter island	A splitter island is a raised or painted area on an approach used to separate entering from exiting traffic, deflect and slow entering traffic, and allow pedestrians to cross the road in two stages.
Circulatory roadway	The circulatory roadway is the curved path used by vehicles to travel in a counterclockwise fashion around the central island.
Apron	An apron is the traversable portion of the central island adjacent to the circulatory roadway that may be needed to accommodate the wheel tracking of large vehicles. An apron is sometimes provided on the outside of the circulatory roadway.
Entrance line	The entrance line marks the point of entry into the circulatory roadway. This line is physically an extension of the circulatory roadway edge line but functions as a yield or give-way line in the absence of a separate yield line. Entering vehicles must yield to any circulating traffic coming from the left before crossing this line into the circulatory roadway.
Accessible pedestrian crossings	For roundabouts designed with pedestrian pathways, the crossing location is typically set back from the entrance line, and the splitter island is typically cut to allow pedestrians, wheelchairs, strollers, and bicycles to pass through. The pedestrian crossings must be accessible with detectable warnings and appropriate slopes in accordance with ADA requirements.
Landscape strip	Landscape strips separate vehicular and pedestrian traffic and assist with guiding pedestrians to the designated crossing locations. This feature is particularly important as a wayfinding cue for individuals who are visually impaired. Landscape strips can also significantly improve the aesthetics of the intersection.

Table 2: Description of Key Roundabout Features (Source: 2010 HCM)

In 1905, Columbus Circle was designed by William Phelps Eno in New York City. This was one of the first traffic circles in the United States and since then they have been a part of the nation's transportation system. In the years following, more large circles and rotaries were built throughout the country. Most designs allowed for merging at high speeds and weaving of vehicles. Contrary to a modern roundabout, entering vehicles, often traveling at high speeds were prioritized. These circles were plagued with high crash rates and congestion and became widely unpopular in the late 1950s. Circles outside the United States experienced similar results. Some were even known to lock up when traffic volumes increased beyond capacity. Vehicles on the circulatory roadway

The United Kingdom is responsible for conceiving the modern roundabout. Its design and operation were meant to address issues that arose in traffic circles. Namely, allowing circulating traffic the right-of-way over entering vehicles. This rule was applied to all circular intersections in 1966. As a result, many circular intersections no longer locked up because vehicles were forced to wait for an appropriate gap before entering. Smaller circular intersections were designed with horizontal curvature of vehicle paths that would sufficiently slow entry and circulating speeds of vehicles.

The results of these changes were improved safety conditions in circular intersections as the number and the severity of crashes decreased (Rodergerdts, 2010). Modern roundabouts are safer and operationally more efficient than older rotaries and traffic circles and have become a common form of intersection in many countries. Many countries have established their own design guidelines and methodology for evaluating operational performance.

2.2 TYPES OF CIRCULAR INTERSECTIONS

There are several other types of circular intersections besides a roundabout. These include rotaries, signalized traffic circles, and neighborhood traffic signals. Figure 2 contains photos of these intersections.

Figure 2: A rotary in Houston, TX, Columbus Circle in New York, NY, and a traffic circle in Austin, TX (from right to left) (Sources: Rodergerdts, 2010, PKSB.com, City of Austin)

A rotary was common in the United States until the 1960s. These circular intersections often had large diameters based on the necessary length of the weaving section needed between entries. The large diameter of these facilities tended to foster high speeds on the circulatory roadway, causing traffic maneuvers to be very difficult. Often rotaries allow entering traffic the right-of-way. As mentioned previously, this causes congestion on the circulatory roadway.

Signalized traffic circles use traffic signals to control entry-circulating points at a circular intersection. This causes them to operate differently than roundabouts that are yield controlled. Vehicles queue up within the circulatory roadway and the signals require progression with one another. They also have pedestrian signals which are not common to roundabouts.

Neighborhood traffic signals are used on local streets as traffic calming devices or merely for decoration. Either uncontrolled or stop-controlled, they do not have raised channelization for guiding vehicles through the circulatory roadway (Rodergerdts, 2010).

2.3 ADDITIONAL DESIGN FEATURES

Along with the design characteristics mentioned earlier in this chapter a roundabout has additional design features meant to improve safety and capacity. However, these features are not necessary in order for a circular intersection to be a roundabout.

2.4 CATEGORIES OF ROUNDABOUTS

Roundabouts have been categorized according to size and number of lanes to facilitate discussion of specific performance or design issues: mini-roundabouts, single-lane roundabouts, and multi-lane roundabouts.

The three main roundabout categories can be further subdivided by their location (e.g., rural, urban, and suburban). For a roundabout in an urban environment, the inscribed circle diameter tends to be smaller due to smaller design vehicles and existing right-of way restrictions. Urban areas also have more extensive pedestrian and bicycle features. Roundabouts located in rural areas allow for higher approach speeds; therefore, more attention is given to visibility, approach alignment, and cross-sectional details. Roundabouts in suburban areas may incorporate features of both urban and rural roundabouts (Rodergerdts, 2010).

2.4.1 Mini-roundabouts

Mini-roundabouts have relatively small inscribed circle diameters and fully traversable central islands, allowing larger vehicles to cross over the central island. However, they are designed to accommodate passenger vehicles without requiring them to drive over the central island. Mini-roundabouts can be useful in such environments where conventional roundabout design is precluded by right-of-way constraints. They are most commonly implemented in low-speed urban environments with average operating speeds of 30 mph (50km/h) or less. Speed control through a mini-roundabout is achieved by the geometric design of the entry and exit legs and the characteristic design that requires most vehicles to travel around the central island.

Mini-roundabouts are less expensive compared than other types of roundabouts because they do not require extensive additional pavement at an intersection. They are perceived as pedestrian-friendly because they are small in size, have short crossing distances, and have very low vehicle speeds entering and exiting the intersection (Rodergerdts, 2010).

2.4.2 Single-lane roundabouts

Single-lane roundabouts have one-lane entries at all legs and one circulatory lane. They are distinguished from mini-roundabouts by their larger inscribed circle diameters (typically 120 to 150 ft [37 to 45 m]), more tangential entries and exits, and non-traversable central islands. Their design, focused on achieving consistent entering and circulating vehicle speeds, allows slightly higher speeds at the entry, on the circulatory roadway, and at the exit. The geometric design of the single-lane roundabout includes raised splitter islands, a non-traversable central island, cross walks, and may include an apron (Rodergerdts, 2010).

2.4.3 Multilane roundabouts

Multilane roundabouts have at least one entry with more than one lane. On some approaches, the entry lanes flare from one to two lanes. The circulatory roadway is wider for a multi-lane roundabout to accommodate vehicles traveling side-by-side. The design allows speeds at the entry, on the circulatory roadway, and at the exit similar to or slightly higher than those for the single-lane roundabouts. The geometric design of the multi-lane roundabout includes raised splitter islands, a non-traversable central island, and may include an apron (Rodergerdts, 2010).

Table 3 summarizes and compares some fundamental design and operational elements for each of the three roundabout categories.

Design Element	Mini Roundabout	Single-Lane Roundabout	Multi-Lane Roundabout
Desirable maximum entry design speed	15 to 20 mph (25 to 30 km/h)	20 to 25 mph (30 to 40 km/h)	25 to 30mph (40 to 50 km/h)
Maximum number of entering lanes per approach	1	1	2+
Typical inscribed circle diameter	45 to 90 ft (13 to 27 m)	90 to 180 ft (27 to 55 m)	150 to 300 ft (46 to 91 m)
Central island treatment	Fully traversable	Raised (may have traversable apron)	Raised (may have traversable apron)
Typical daily service volumes on 4-leg roundabout below which may be expected to operate without requiring detailed capacity analysis (veh/day)*	Up to approximately 15,000 veh/day	Up to Approximately 25,000 veh/day	Up to approximately 45,000 veh/day for two-lane roundabout

*** Operational analysis needed to verify upper limit for specific applications or for roundabouts with more than two lanes or four legs.**

Table 3: Comparison of roundabout categories (Source: Rodergerdts, 2010)

Chapter 3- Site Description

Both sites chosen for this thesis exhibited high enough traffic volume during peak periods of the day for instances of gap acceptance to occur frequently. Both differ in setting, geometry, and traffic volumes so a comparison between the two scenarios can be made. Both closely follow design specifications located in the FWHA Roundabout Guidelines and therefore serve as appropriate case studies for current federal guidelines.

3.1 SOUTHLAKE, TEXAS ROUNDABOUT

A single lane roundabout located in Southlake, Texas provides the intersection of East Continental Boulevard and South Carroll Avenue. Since this example intersection includes the essential characteristics of a modern roundabout, it was selected for field monitoring and analysis. The northwest and southeast corners of the roundabout are open green space. There is a commercial structure on the northeast corner of the roundabout and a residential neighborhood on the southwest corner. The surrounding area is mostly residential and commercial. The inscribed circle diameter is approximately 130 feet and the angles between approach centerlines are all approximately 90 degrees. Average traffic volume during the morning peak hours is about 1200 vph versus about 1150 vph during the afternoon peak hours. Heavy vehicle percentage for the morning and afternoon are 2.6% and 5.2% respectively. Although both morning and afternoon video footage was used during the model validation process only data from the afternoon video footage was used during in-depth capacity analysis.

Figure 3: East Continental Boulevard and South Carroll Avenue, Southlake, Texas (Source: Google Maps)

3.2 SAN ANTONIO, TEXAS ROUNDABOUT

The Fulton Avenue & Blanco Road roundabout is a single lane roundabout in an urban area of San Antonio, Texas. With an inscribed circle diameter of about 90 feet it is on the low end of inscribed circle diameter for single-lane roundabouts. Average traffic volume during the morning peak hours is about 500 vph. Heavy vehicle percentage observed during the morning peak is 2.3%.

Figure 4: Fulton Avenue and Blanco Road, San Antonio, Texas (Source: Google Maps)

Chapter 4 - Software and Procedures

VISSIM 5.20 and SIDRA INTERSECTION are the software packages used during analysis for this work. VISSIM is a microsimulation software package used for modeling urban road and transit networks. Gagnon (2008) views VISSIM as the most "versatile" when compared to SIDRA and other roundabout analysis models.

SIDRA's primary function is to assist in design and evaluation of signalized intersections, signalized pedestrian crossings, single point interchanges, roundabouts, roundabout metering, two-way stop control, all-way stop control, and give-way/yield sign control. SIDRA is a micro-analytical traffic evaluation tool for isolated intersections that uses lane-by-lane and vehicle drive-cycle models in conjunction with an iterative approximations method for calculating capacity and performance statistics estimates. SIDRA predicts performance statistics including delay and queue length.

In this work, SIDRA is used for analysis of roundabout entry lane capacity. The results will be compared to those generated by VISSIM and the Highway Capacity Manual (HCM) 2010 roundabout entry lane capacity curve. The HCM roundabout entry lane capacity curve is available in NCHRP 672 and the 2010 Highway Capacity Manual. The SIDRA User Manual maintains that capacity estimations are sensitive to changes in approach and circulated lanes use, origin-destination traffic patterns, and the length of queues on roundabout approaches.

SIDRA can be calibrated for local conditions and is accepted by the U.S. Highway Capacity Manual, the current FHWA Roundabout Guide, NCHRP 572

(Rodergerdts, 2007), and many local roundabout guides. SIDRA comes equipped with various intersection configuration templates. Figure 5 shows the SIDRA interface and the template used for analysis.

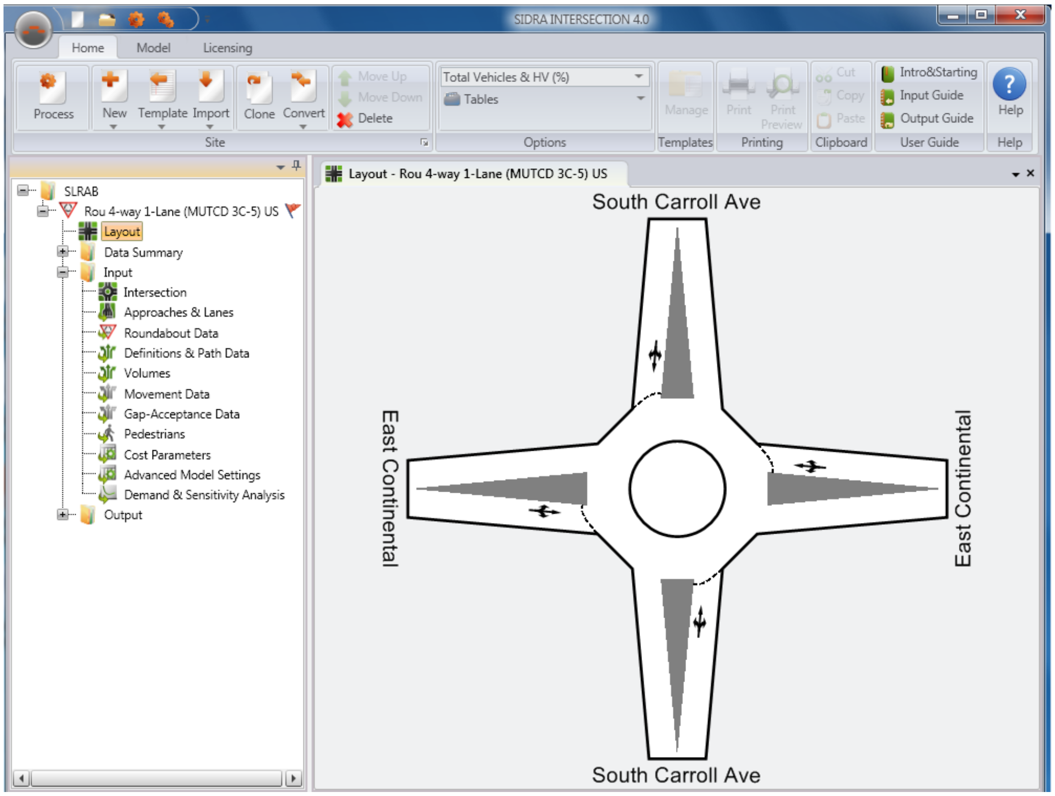


Figure 5: SIDRA interface

Once an appropriate template is selected the characteristics of the roundabout can be adjusted using the Input Dialogs. These are labeled in Figure 5. Input Dialogs include Intersection, Approaches and Lanes, Roundabout Data, Freeway, Roundabout Metering, FHWA Roundabout Data, Definitions and Path Data, Volumes, Movement Data, Priorities, Gap Acceptance Data, Phasing and Timing, Pedestrians, Cost Parameters, Advanced Model Settings, Demand & Sensitivity Analysis. When Input Dialogs are filled out and adjusted, SIDRA processes the input and provides a range of outputs. As mentioned previously, in SIDRA a template (such as the one shown in Figure 5) is chosen that best matches the roundabout in question. Other geometric features are specified in Input Dialogs including lane width, circulatory roadway width, and approach distance. The output of most interest during this analysis was Lane Capacity located in the Lane Summary section of the outputs. This is the value that can be compared most directly to VISSIM and HCM capacity results.

Few studies have been done that compare roundabout performance factors such as capacity from analysis models like SIDRA to field measurements (Gagnon, 2008). Akcelik (2003) used capacity data from a United States roundabout and compared it to four analytical models including SIDRA, the UK linear regression model, the HCM 2000 model, and the Australian National Association of Australian State Road Authorities 1986 model. NCHRP 3-65 was funded to improve safety estimations for roundabouts in the U.S., however, capacity estimates from RODEL and SIDRA were compared. RODEL, a roundabout design software based on empirical models, overestimated delay while SIDRA underestimated it.

For VISSIM, an aerial image of the intersection was imported and scaled, and links and connectors were organized over the image to match the geometry of the roundabout. This is depicted in Figure 6. Priority rules were designated at each entry leg so traffic in and around the roundabout functioned accurately. That is to say vehicles approaching the roundabout on the entry legs yield to vehicles traveling on the circulatory roadway before entering.

Figure 6: Screen shot of VISSIM model for Southlake roundabout

In VISSIM, capacity results are taken from the output. The entry lane capacity curve provided in NCHRP 672 supply the HCM values. Information on what parameters were adjusted in VISSIM and SIDRA can be found in the following section, Calibration and Validation. It is important to note that although VISSIM performs microscopic traffic simulation the software does not contain a capacity model (Wei, 2011).

For more information on SIDRA and VISSIM, see Akcelik and Associates (2009) and PTV (2007), respectively. Calibration of the SIDRA and VISSIM models is explained in detail in the following section.

Chapter 5 – Calibration and Validation

Gagnon (2008) found that calibration of VISSIM and SIDRA models "have a significant impact on improving results". Calibrating models reduced average percent error by as much as 39% for SIDRA and 68% for VISSIM. However, Gagnon noted that the calibration process varies from site to site so there is no one set of calibration parameters for all roundabouts. It was recommended that future research be conducted on developing a classification of locations so parameters could be established for roundabouts with similar characteristics.

Very few studies discuss validation and calibration of microscopic simulation models such as VISSIM. Kinzel (2004) and Oketch (2004) have expressed a need for such research. Kinzel and Trueblood (2004) compared microscopic simulation and analytical-type deterministic models for operational parameters such as follow-up headway, speed and critical gap. They discuss how parameters vary but do not make any comparisons to field data. In their capacity analysis of roundabouts with flared entry and double lanes using SIDRA, VISSIM, RODEL, and PARAMICS (a microscopic traffic simulation software), Stanek and Milan (2005) did not include any information on calibration techniques and did not compare results to field data. When considering high-capacity roundabouts and their use in smart signalized streams, Bared and Edara (2005) based calibration on smooth simulation flow. Capacity results were compared to field data from 15 roundabout sites.

In this work, VISSIM and SIDRA models were calibrated using data collected from roundabouts in Southlake and San Antonio, Texas. Parameters such as volume, speed, and heavy vehicle percentage were changed to match that of the roundabout in question. All parameters for which no data was collected were left at their default values.

One of the most important parameters for calibrating the models is vehicle speed. VISSIM requires a probability distribution of driver speeds as they enter the roundabout. Speed distributions were developed using 40 speed readings from vehicles that did not have to yield before entry and were traveling straight through the roundabout on recorded video footage. These readings were used to create a distribution of speed that was then input into VISSIM. Using this distribution, VISSIM can reflect the stochastic nature of traffic speeds realistically. An average speed value was input into SIDRA for each approach into the circulatory roadway.

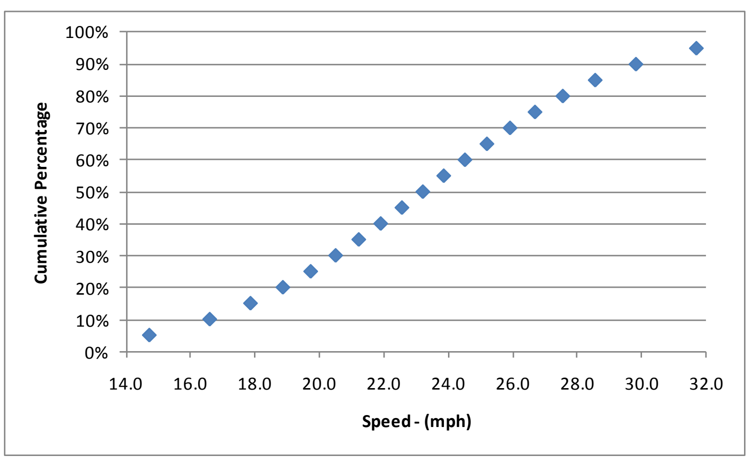


Figure 7: Speed distribution for morning peak period at Southlake roundabout

Heavy vehicle percentage was calculated from recorded video footage and used in VISSIM and SIDRA so vehicle composition approximately matched that of the actual roundabout.

Two methods of model validation were used to compare results from the VISSIM model to the video footage of the roundabout. This process was meant to ensure that the models were calibrated accurately and could simulate the roundabout realistically. These methods include an entry decision binary comparison and travel time comparison. For the entry decision comparison, the percentage of vehicles that chose to enter the roundabout while there was a vehicle on the approaching fourth of the circulatory roadway was calculated from VISSIM and the video footage. Figure 8 indicates the approaching fourth for the southern entry leg using red dotted lines. The difference between the two percentages could indicate if driver behavior is comparable between the model and the actual roundabout during peak periods. This validation method is important because driver behavior has been shown to affect roundabout performance significantly. This is explained in further detail in Chapter 5: Capacity Analysis.

Figure 8: Travel time comparison time stamp points.

Table 4 shows the entry decision percentages for Southlake during the morning and afternoon peak hours and San Antonio during the morning. The high p-values (corresponding to statistical tests of the differences between percentages) indicate that there is no significant difference between the video and VISSIM and therefore VISSIM is simulating driver entry decision accurately for all models.

Roundabout	VISSIM	Video	p-value
Southlake AM	35.9%	38.3%	**0.6707**
Southlake PM	46.9%	50.8%	**0.5008**
San Antonio	34.1%	30.6%	**0.7370**

Table 4: Entry decision percentages

The travel time comparison is meant to investigate how accurately VISSIM models the trajectory of vehicles through the curves of the roundabout and if the speed distribution used in VISSIM is appropriate. Figure 9 shows the points where time stamps were taken for each vehicle in VISSIM at the Southlake roundabout. Time stamps were taken at approximately the same points from the video footage. Forty sets of time stamps were retrieved from both VISSIM and the video and the average travel times between points were compared using a two-sided two-sample t-test. This comparison provides insight on how well the speed distributions compare for VISSIM and the video and how accurately VISSIM is modeling the speed of the vehicles navigating the roundabout.

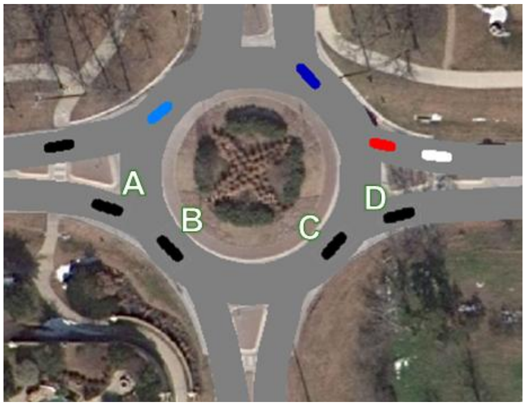


Figure 9: Travel time comparison time stamp points

Table 5 shows the travel time averages compared using a two-sided two-sample t-test with an assumed alpha-level of 0.05. The bolded values are those where the difference between the means is not significantly different from zero. Through this comparison Southlake PM (i.e. during the afternoon peak period) and San Antonio were concluded to be the best models since VISSIM was able to simulate trajectory and speed the most accurately. Where the differences were statistically significant, the actual difference in the average travel time is still relatively small. Further investigation is needed, however, to determine why such differences occurred.

		Average Time [seconds]			
		A to B	**B to C**	**C to D**	**A to D**
Southlake AM	VISSIM	0.90	2.34	0.65	3.88
	Video	1.34	3.61	1.10	6.05
Southlake PM	VISSIM	**1.28**	3.66	**1.23**	6.17
	Video	**1.20**	5.03	**1.18**	7.40
San Antonio	VISSIM	**1.79**	**3.65**	**1.92**	**7.36**
	Video	**1.84**	**3.33**	**2.04**	**7.22**

*__bold__ values indicate that the difference between the means is not significantly different from zero (at the alpha=0.05 level)

Table 5: Average travel times

The VISSIM models for Southlake PM and San Antonio model trajectory, speed, and entry decision accurately so they were concluded to be the best models overall. Both are used in the capacity analysis of this thesis. The calibration and validation methodology presented in this thesis shows that the results of VISSIM can be reasonably validated.

Since SIDRA is a simpler software package than VISSIM, the SIDRA models could not be validated in the same way. A comparison of approach leg capacity estimates from the HCM curve, SIDRA, and VISSIM, is undertaken in the following section.

Chapter 6 - Capacity Analysis

6.1 DRIVERY BEHAVIOR AND CAPACITY

NCHRP 572 highlights driver behavior as the variable that affects roundabout performance the most. Variation in driver behavior between roundabout sites coincided with different levels of capacity. Second to driver behavior is the number of lanes in a roundabout. Varying other aspects of roundabout geometry such as lane width did not substantially change capacity.

Since driver behavior seems to have the greatest affect on roundabout performance, NCHRP 672 stresses the importance of taking into account local driver behavior when calibrating models to achieve accurate capacity estimates. More information on how this study accounts for local driver behavior in its models can be found in the Chapter 5: Calibration and Validation.

6.2 ENTRY LANE CAPACITY ACCORDING TO THE 2010 HIGHWAY CAPACITY MANUAL

Capacity is a performance gauge and a very important design parameter. The 2010 Highway Capacity Manual dedicates an entire chapter to roundabout capacity methodology. The focus of the capacity methodology is on the operation of roundabouts. The methodology assumes that a roundabout is isolated. In other words, it does not take into account the effect of nearby traffic control devices. The chapter also discusses alternative tools capable of modeling situations that the analytical methodology they offer cannot.

The 2010 HCM methodology for roundabouts uses a combination of regression and analytical models. Regression models "use field data to develop statistically derived relationships between geometric features and performance measures such as capacity and delay". Analytical models are "based on traffic flow theory combined with the use of field measures of driver behavior, resulting in an analytic formulation of the relationship between those field measures and performance measures such as capacity and delay."

Gap-acceptance models are analytical and are often used for analyzing unsignalized intersections because of the ability to incorporate driver behavior directly. Parameters can be adjusted to make models site-specific. The limitation of gap acceptance models is that they don't always capture all of the behavior that is observed. Gap-acceptance models that incorporate limited and reverse priority are complex and hard to calibrate. In instances where driver behavior characteristics are not entirely known, regression models become useful.

The 2010 Highway Capacity Manual largely bases its entry capacity equations on data collected from U.S. roundabouts in 2003 for NCHRP Project 3-65. The methodology is comprised of several simple, empirical regression models and gap-acceptance models that are meant to predict capacity for roundabouts with up to two entry lanes and up to one bypass lane approach.

According to NCHRP 572, the models developed by the Highway Capacity Manual can be calibrated for local conditions by adjusting critical headway and follow-up headway. However, Wei maintains that results from calibrated models do not typically represent flow-rates observed in the field. Wei developed a streamlined process for developing new roundabout capacity models for local conditions. The model developed in the paper's case study produces capacity values higher than the HCM model. Wei explains that this is typically the case when comparing capacity estimates for roundabouts that have been in operation for a long time to the HCM model results.

6.2.1 Development of single-lane model

The capacity equation presented in the 2010 HCM is derived from a 2000 HCM model equation. The 2010 HCM shows how the HCM 2000 model can be changed into a regression-like form. The HCM 2000 offers the following equation:

$$q_{e,\max} = \frac{q_c \exp(-q_c t_c / 3600)}{1 - \exp(-q_c t_f / 3600)} \quad (1)$$

where,

$q_{e,max}$ = entry capacity (veh/h)

q_c = conflicting circulating traffic (veh/h)

t_c = critical headway (s)

t_f = follow-up headway (s)

The previous equation can be simplified into this form:

$$q_{e,\max_c} = \frac{3600}{t_f} \exp\left(-\frac{t_c - t_f / 2}{3600} q_c \right) \quad (2)$$

which is equivalent to this form:

$$q_{e,\max} = A \cdot \exp(-B \cdot q_c) \quad (3)$$

where,

$$A = 3600 / t_f$$

$$B = ((t_c - t_f / 2) / 3600$$

t_c = critical headway (s)

t_f = follow-up headway (s)

Figure 10 shows the capacity estimate using the HCM 2000 model and average field values for the gap parameters, and the capacity estimate using the exponential regression of the data collected at U.S. roundabouts in 2003. The intercept and slope predicted by the exponential regression of 1129 and 0.0010 compare with the HCM intercept of (3600/tf = 3600/3.2=) 1125 and slope of [(tc-tf/2)/3600=(5.1-3.2/2)/3600=] 0.0010. These results make application of the exponential regression more practical. This process has the potential to be used to calibrate constants against local data.

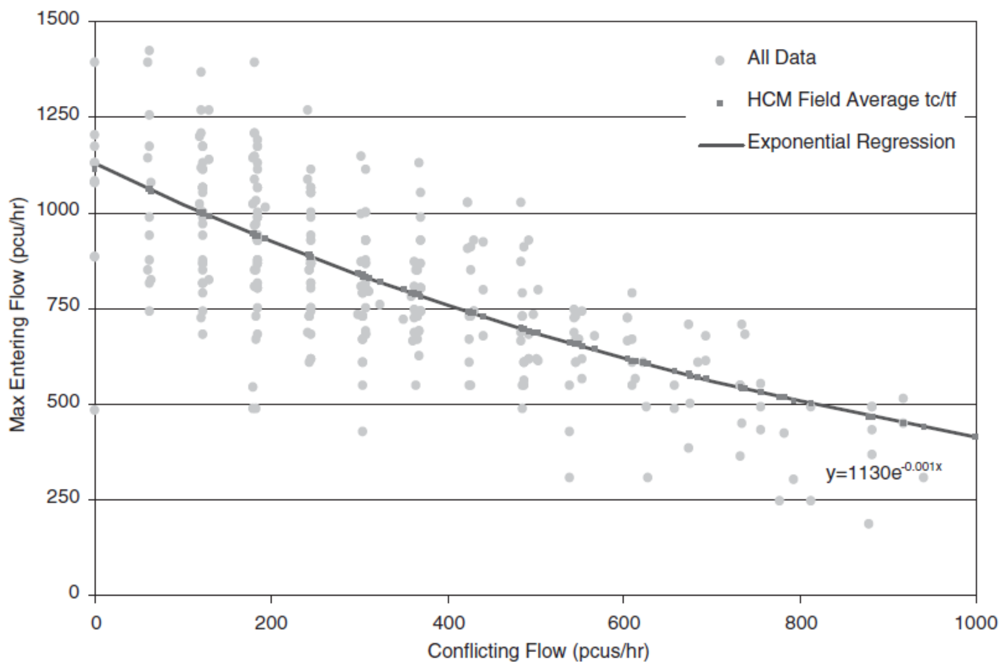


Figure 10: Capacity using HCM and exponential regression models (Source: NCHRP 572/2010 HCM)

The previous discussion is the basis for this equation which is recommended by the 2010 HCM for the entry lane capacity at single-lane roundabouts:

$$c = 1130 \cdot \exp(-0.0010 \cdot v_c) \quad (4)$$

where,

$c = q_{e,max}$ = entry capacity (veh/h)

$v_c = q_c$ = conflicting circulating traffic (pcu/h)

The primary explanatory variable for this model is the conflicting flow measured in passenger cars per hour (pc/h). Primary conflicting flow is the conflicting flow that travels along the circulatory roadway in front of the entry leg in question. Generally speaking, as conflicting flow increases the capacity of a roundabout entry decreases.

Figure 11 is a plot of the capacity equations provided by the HCM. The bold line corresponds to Equation 4.

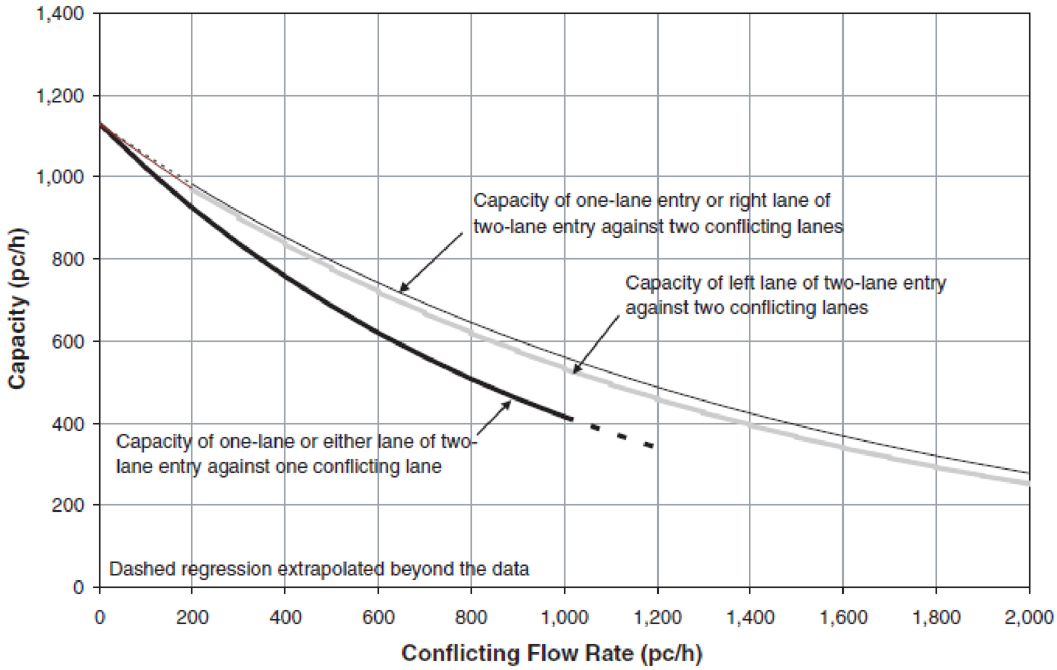


Figure 11: Entry Lane Capacity (Source: NCHRP 672)

6.3 EXTENDING THE HIGHWAY CAPACITY MANUAL EQUATIONS

The HCM points out the capacities of United States roundabouts are lower than that of roundabouts in other countries. This is attributed to the lack of familiarity of drivers in the United States with roundabouts since they are largely uncommon. It is predicted that the capacity of roundabouts in the United States will improve over time as drivers get used to roundabouts and they are forced to use them more efficiently due to increasing demand.

The 2010 HCM states that the "capacity of a roundabout approach is directly influenced by flow patterns." They identify the flows of interest as entering, exiting, and circulating flow. Figure 12 shows the different flows associated with a roundabout. Total flow is comprised of the flow of vehicles that conflicts with the entry-lane in question (conflicting flow) and the flow of vehicles that exits the circulatory before crossing the path of the entry (exiting flow).

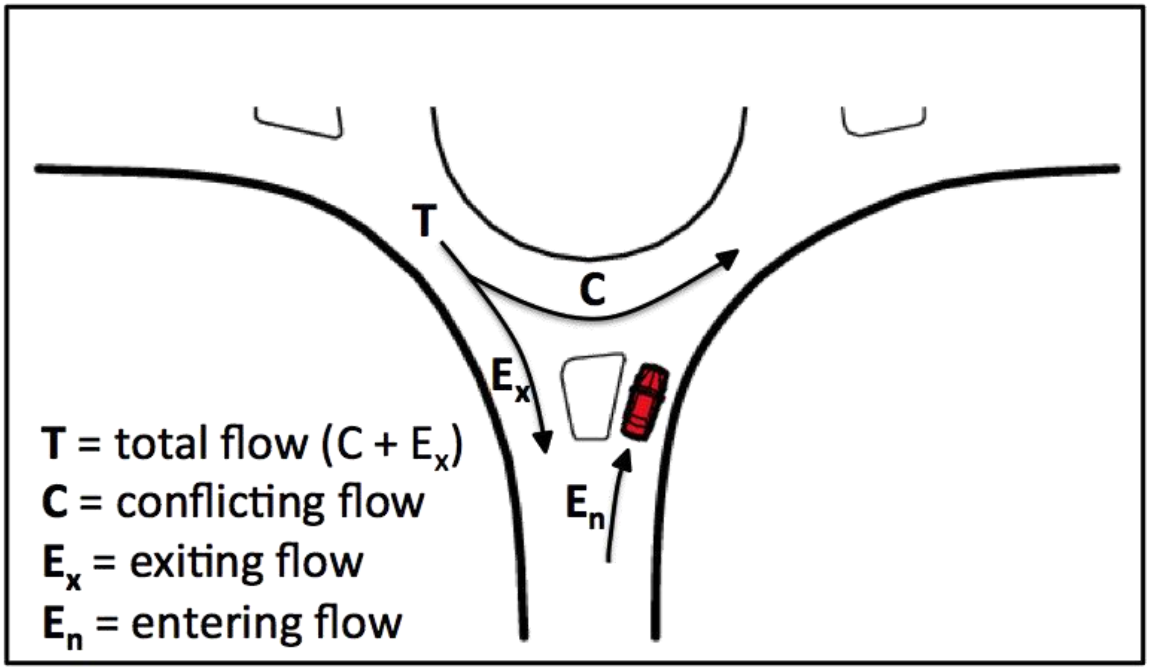


Figure 12: Roundabout vehicle flows

NCHRP 672 recognizes that the effect of exiting flow has the potential to affect the capacity prediction accuracy. It is often unclear to drivers attempting to enter a roundabout if cars approaching on the circulatory roadways will exit the roundabout before crossing their path or not. This uncertainty can affect a driver's decision to enter the circulatory roadway or not. The manual explains that including the effect in its capacity models did not significantly improve the overall fit to their data and so it was not included in the methodology. However, since the behavior is observed in the field “refinements to assumptions may suggest otherwise”. They assert that “in practice the exiting flow does not impact all entering vehicles, and the exact extent of the influence of exiting vehicles has not been determined.

Hagring (2001) was able to show that the share of exiting vehicles “could have a large effect on the entry capacity depending on entry drivers’ abilities to detect exiting vehicles.” Through simulation, Hagring (2001) found that entry capacity increased as the proportion of exiting vehicles increase when the major flow of a roundabout is constant. Hagring (2001) (as well as Troutbeck (1990)) attributed the effect of exiting vehicles on entry capacity to the geometry of the approach, major stream vehicle speeds, and the percentage of major stream exiting vehicles.

Troutbeck (1990) collected data at roundabouts in Australia and concluded that exiting vehicles had very little effect on entry capacity. He recommended that exiting traffic be considered when circulating speeds are high and also when differences between circulating and exiting travel paths are difficult to recognize based on roundabout geometry.

Mereszczak (2006) expanded on Hagring’s (2001) study by comparing capacity estimates with and without exiting traffic with capacities measured in the field at U.S. roundabouts. They concluded that including exiting vehicles results in an improved estimate of capacity. Specifically, an overall reduction in capacity prediction error of almost 20% was observed. From this, they recommend that exiting vehicles be included in capacity estimation for U.S. roundabout approaches and further research be conducted to find the precise way exiting vehicles should be taken into account. Although, they do warn that despite the improved capacity estimation significant errors in capacity prediction are still prevalent as seen in Figure 13.

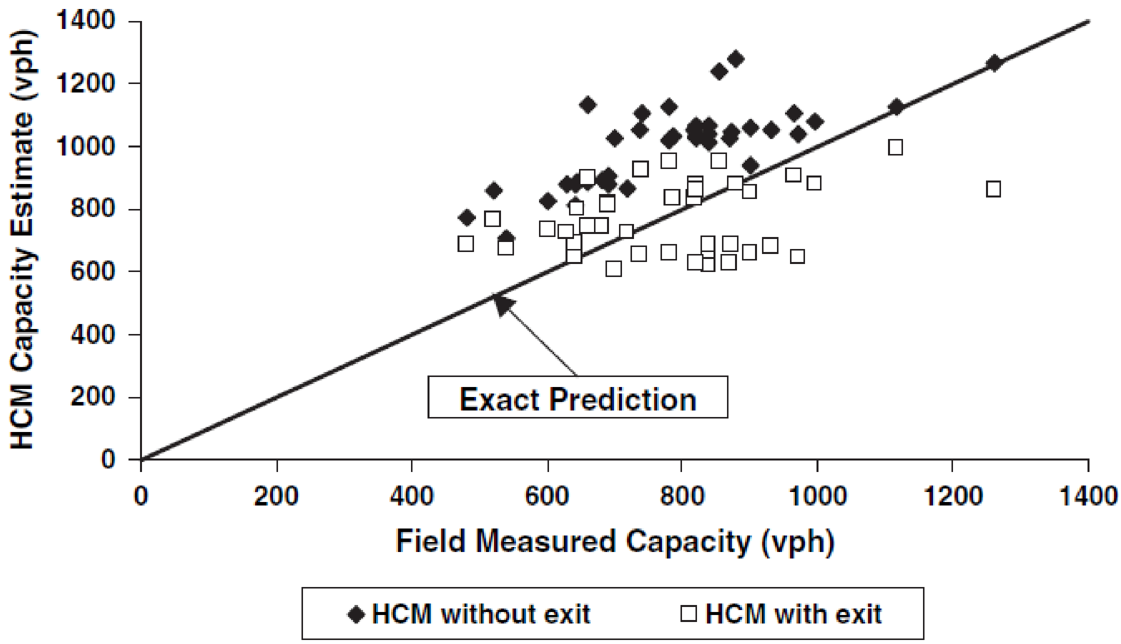


Figure 13: Merezcazak's capacity estimates compared with measured capacities (2006)

Entry decision is included in the model validation process to assure that VISSIM accurately models entry decision behavior. See Chapter 5: Calibration and Validation of this work for more information. When the term "exiting traffic" is used it is in reference to the traffic exiting at the leg where entry capacity is being measured. This work explores the effects of exiting vehicles on capacity predictions.

Along with exiting traffic, origin-destination patterns have also been identified as a variable that influences the capacity of a given entry. NCHRP 572 does not explore its effects and the 2010 HCM manual does not include it in capacity models. Akcelik (2004) found that although unbalanced flows did not prove to be an issue when total demand was low it did become problematic when traffic increased to toward medium demand levels. Case studies showed that not only does circulating flow rate affect capacity but the characteristics of approach flows that create the circulating flow do as well. They recommend that the amount of queuing on the approach road, circulating lane use, priority sharing, and priority estimates be taken into account when determining capacity. Part-time metering signals during peak travel times have been used as a solution to this issue.

Krogscheepers (2000) did a study using the simulation program TRACSIM and found that delay is responsive to the change in balance of the circulating flows. Specifically, if the majority of traffic is originating from the approach directly to the left of the approach being considered then delay is usually higher. But if the same traffic volume is coming from the approach directly across the roundabout from the approach being considered the average delay is lower. As a result, the origin and destination of traffic along with the amount of traffic at various approaches affects overall roundabout performance. Krogscheepers (2000) also notes that although SIDRA attempts to account for the effect of one approach volume overshadowing other approaches it is not sensitive to location.

Origin-destination pattern effects are investigated in this study to see if capacity is sensitive to where circulating and exiting traffic is originating. Note that the approach leg capacity analyses conducted in this research were conducted on a roundabout's southern-most leg. Several different origin distribution patterns are used including:

- Southbound (SB) – All conflicting and exiting traffic originates from the northern entry.
- Eastbound (EB) – All conflicting and exiting traffic originates from the western entry.
- EVEN – Conflicting and exiting traffic is evenly distributed between the three legs other than the leg whose entry capacity is being considered.
- 25/50/25 – Meant to simulate a roundabout with an obvious major and minor street, 25% of the conflicting and exiting flow originates from the western entry, 50% of the conflicting and exiting flow originates from the northern entry, and the remaining 25% of conflicting and exiting flow originates from the eastern entry.

This work also analyzes the effect of the speed distribution of a roundabout on entry capacity. The mean of the observed speed distribution from the Southlake roundabout during the PM peak is increased and decreased to explore this relationship. Comments are made regarding the relationship between mean speed and inscribed circle diameter using the characteristics of both the San Antonio and Southlake roundabout.

In SIDRA, capacity is output based on empirical equations. In VISSIM, researchers estimated capacity by placing a high demand on the southern-most approach leg and measuring how much of that demand was able to enter the roundabout in a given period of time. All vehicles approaching from the southern-most leg were assumed to exit using the northern-most leg.

Chapter 7 – Analysis and Results

7.1 EFFECTS OF EXITING FLOW AND DISTRIBUTION OF THE ORIGIN OF CONFLICING TRAFFIC

7.1.1 Southlake - PM Peak

As seen in Figure 14, results from VISSIM show that the roundabout capacity does differ depending on the exiting flow. Therefore, depending on the exiting flow rate, the capacity estimate given by HCM may not be accurate. When exiting flow is low and conflicting flow is below approximately 800 vph the HCM underestimates capacity and then overestimates capacity beyond this threshold.

Exiting flow rates of approximately 760 and ~1100 vph were used because lower rates had no impact and higher rates were not able to enter the roundabout. Values of exiting flow are approximate because although this is the designated exiting flow the resulting flow does not turn out to be exactly this value due to the randomness inherent to the simulation. Table 6 shows the difference in capacity when exiting traffic was added compared to zero exiting traffic. Bolded values are differences greater than 100 vph, which the researchers considered to be significant. These scenarios were explored more thoroughly in capacity analysis.

Conflicting traffic (vph)	Exiting traffic (vph)	Entry Lane Capacity with exiting traffic (vph)	(Capacity without exiting) - (Capacity with exiting) (vph)
383	150	959	32
	300	920	71
	766	800	**191**
	1149	714	**277**
479	150	837	35
	300	794	78
	766	740	**132**
	1149	649	**223**
574.5	150	746	23
	300	720	49
	766	637	**132**
	1149	595	**174**
766	150	560	15
	300	548	27
	766	480	95
	1149	530	45
900	150	433	35
	300	428	40
	766	406	62
	1149	466	2
1000	150	368	23
	300	361	30
	766	376	15
	--	--	--

Table 6: Comparison of entry lane capacity results for Southlake – PM Peak

With the addition of ~760 vph exiting traffic at the entry leg, the HCM curve predicts the VISSIM results accurately below 600 vph of conflicting traffic. However, data points do not tend to fit the HCM curve beyond this range. The trend of the data points continues on a downward linear path as conflicting vph increases and the HCM curve overestimates capacity. When exiting traffic flow is increased to ~1100 vph the HCM overestimates capacity for the entire range of values. The differences become greater as conflicting traffic increases.

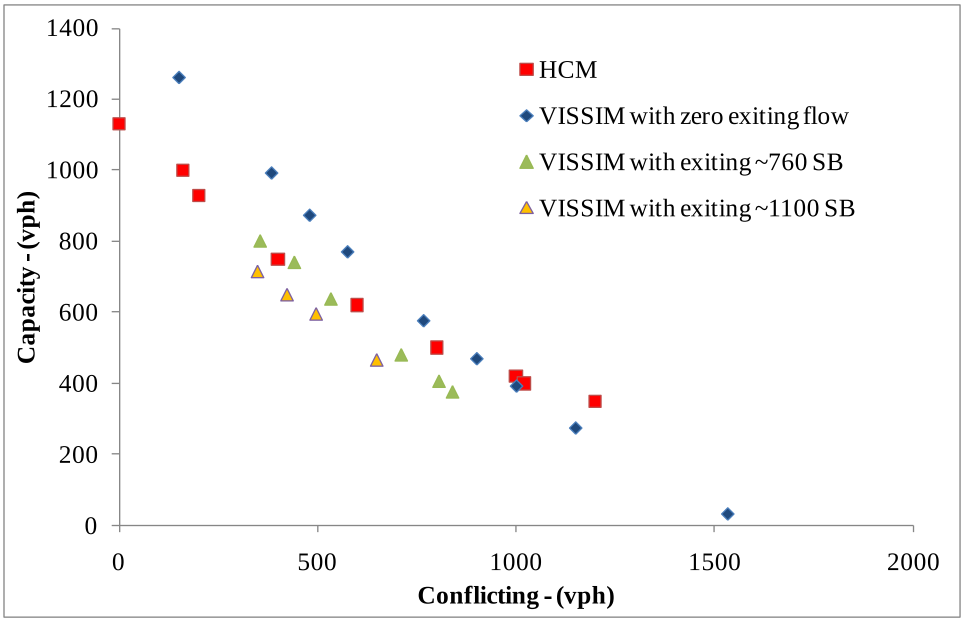


Figure 14: VISSIM results for entry lane capacity

As seen in Figure 15, VISSIM results did not show significant variation in capacity depending on the distribution of the origin of the conflicting traffic (i.e., SB, EVEN, and 25/50/25) when the exiting traffic flow rate was ~760 vph. All data points in the range provided tend to follow the HCM curve below 600 vph of conflicting traffic. However, when exiting traffic is increased to ~1100 vph capacity becomes more variable depending on the distribution of the traffic origin. In all cases besides EVEN, capacity is overestimated by the HCM curve. This could indicate that when exiting traffic volume is high the HCM curve is better suited to predict entry lane capacity for roundabouts when traffic is evenly distributed across the legs.

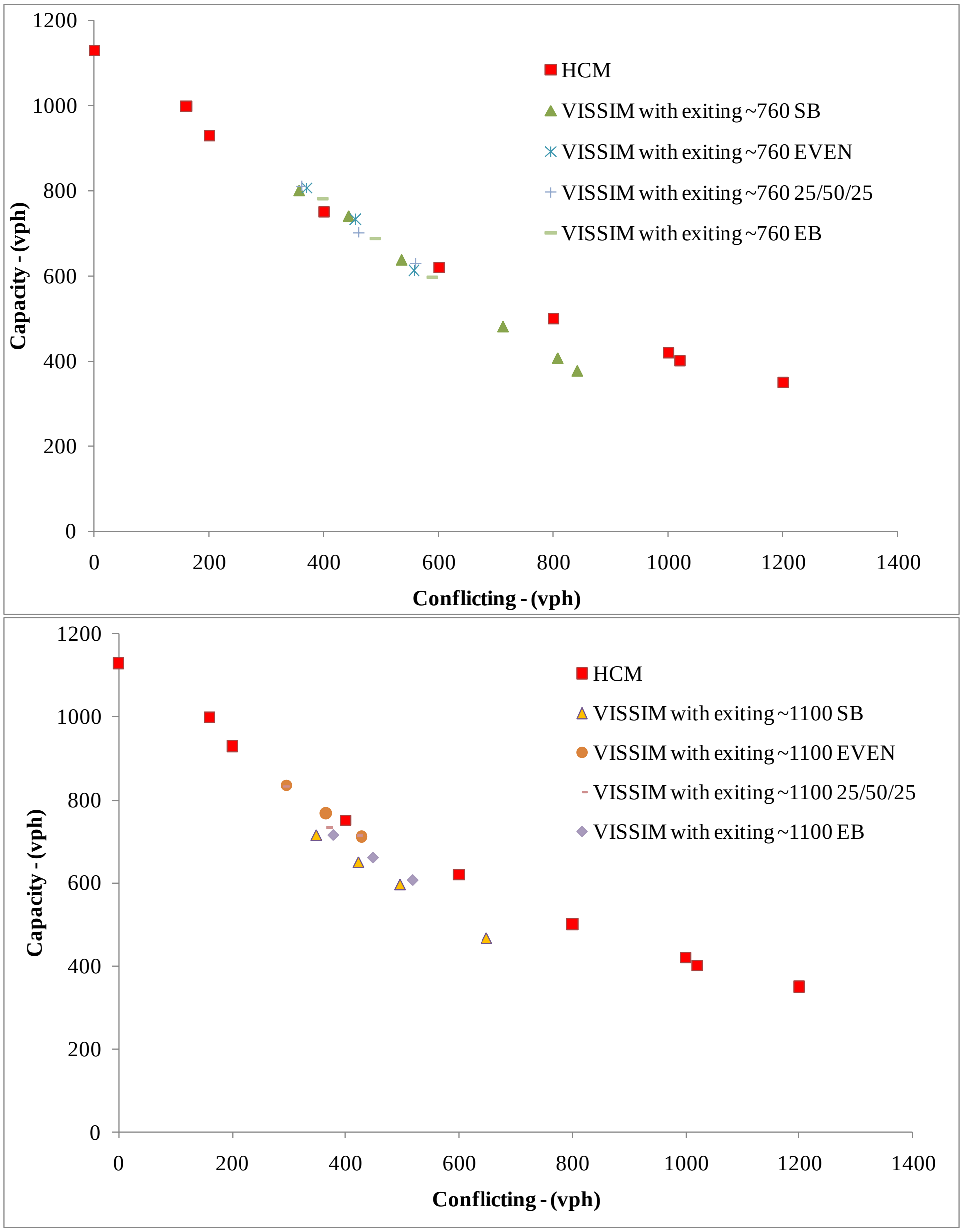


Figure 15: VISSIM entry lane capacity results with multiple distributions of the origin of traffic for ~760 vph and ~1100 vph exiting traffic

Results from SIDRA when exiting traffic is not taken into account predict capacity greater than that of the HCM curve as in Figure 16. It should be noted that results from SIDRA are largely based on the roundabout capacity equations from HCM 2010 and NCHRP 572. This conflicts with Capacity does not differ substantially when there is less than ~760 vph of exiting flow. When exiting flow is increased to ~1100 vph the capacity decreases and is comparable to that predicted by the HCM.

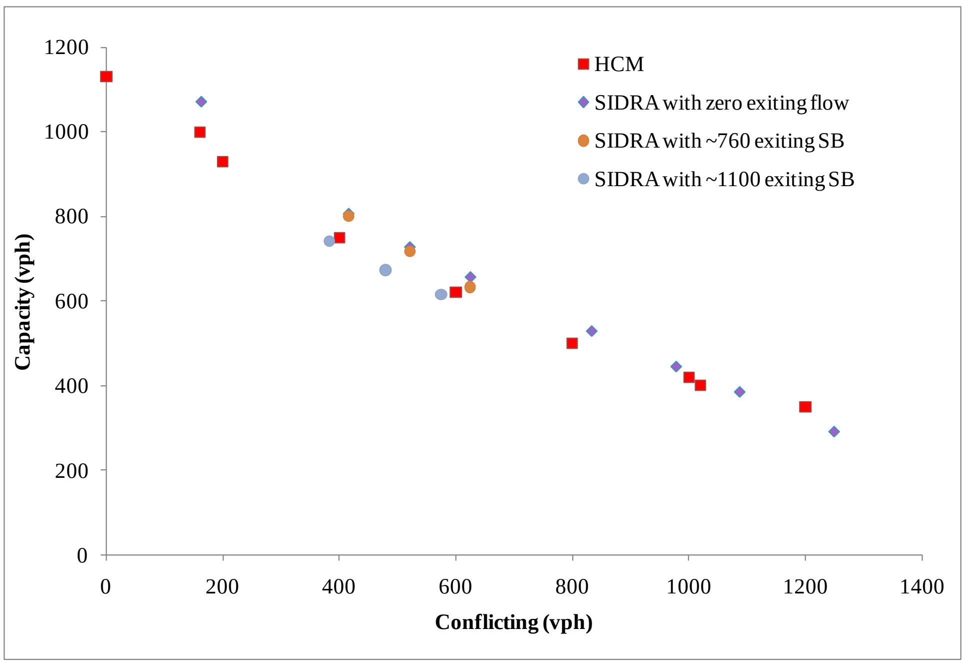


Figure 16: SIDRA results for entry lane capacity

As seen in Figure 17, capacity varies somewhat depending on the distribution origin of conflicting traffic when exiting traffic is ~760 vph. Capacity is lower and more similar to that predicted by the HCM curve when traffic is evenly distributed or distributed as in the 25/50/25 scenario. Variation in capacity appears to diminish when exiting traffic increases to ~1100 vph.

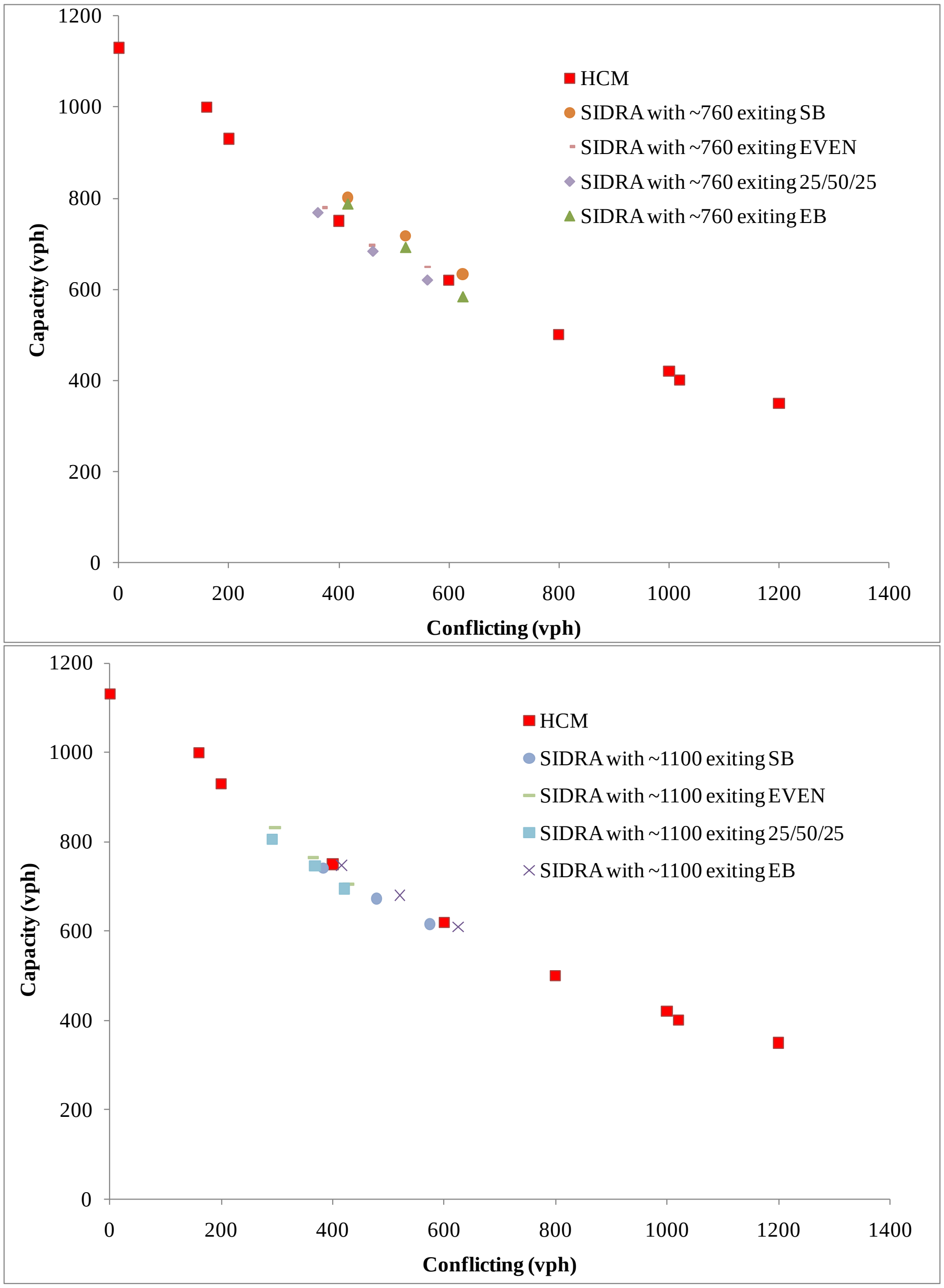


Figure 17: SIDRA entry lane capacity results with multiple distributions of the origin of traffic for ~760 vph and ~1100 vph of exiting traffic

For Southlake, the Highway Capacity Manual equation appears to give a reasonable estimate of capacity until conflicting flow goes above 600 vph when exiting flow is ~760 vph. However, beyond this threshold, and when exiting flow increases to ~1100 vph, the HCM overestimates capacity. Capacity results from SIDRA do not tend to be affected by exiting traffic to as great an extent as VISSIM. VISSIM predicts substantially lower capacity for exiting traffic of 1100 vph than SIDRA which tends to follow the trend of the HCM curve. Results from SIDRA and VISSIM are comparable for a roundabout of this nature so either software is recommended for use in entry lane capacity analysis.

7.1.2 San Antonio

Both values ~500 and ~700 vph exiting flow were used because lower rates had no impact and higher rates were not able to enter the roundabout. Table 7 shows the difference in capacity when exiting traffic was present compared to zero exiting traffic. Bolded values are those greater than 100 vph, which the researchers considered to be notably different. These scenarios were explored more thoroughly in capacity analysis.

Conflicting traffic (vph)	Exiting traffic (vph)	Entry Lane Capacity with exiting traffic (vph)	(Capacity without exiting) - (Capacity with exiting) (vph)
329	150	594	51
	507	516	**129**
	761	458	**187**
	1014	505	**140**
507	150	441	48
	507	364	**125**
	761	395	94
	1014	423	66
634	150	323	37
	507	288	72
	761	339	21
	1014	352	8
761	150	161	80
	507	248	-7
	761	249	-8
	1014	--	--

Table 7: Comparison of entry lane capacity results for San Antonio

As seen in Figure 18, capacity values from VISSIM where exiting traffic is not taken into account fall well below the HCM curve. Capacity continues to decrease when exiting flow is taken into account. VISSIM results indicate that the HCM roundabout capacity curve is not appropriate for roundabouts with such a small inscribed circle diameter. Based on the results from VISSIM, practitioners should be cautioned against using the HCM curve for smaller roundabouts as capacity will be largely overestimated.

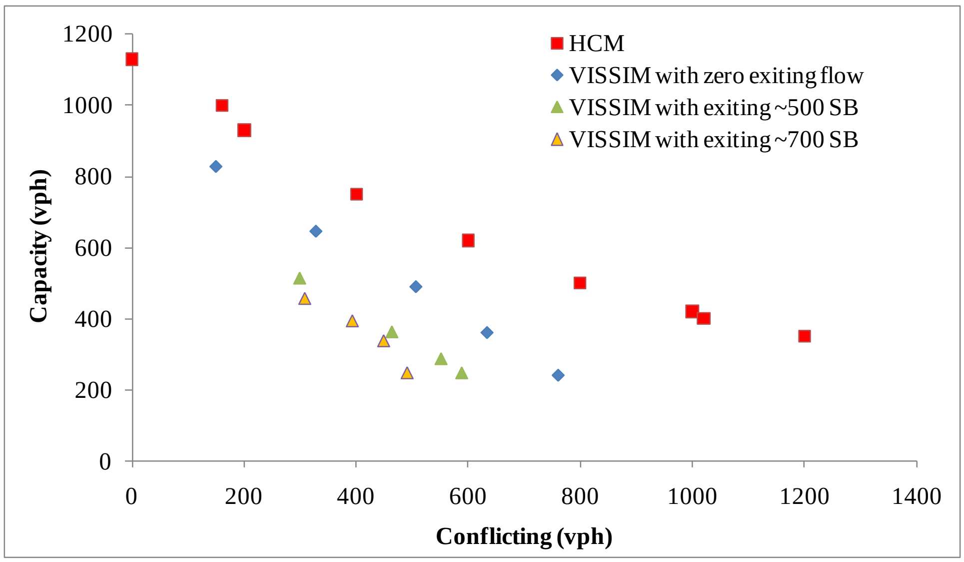
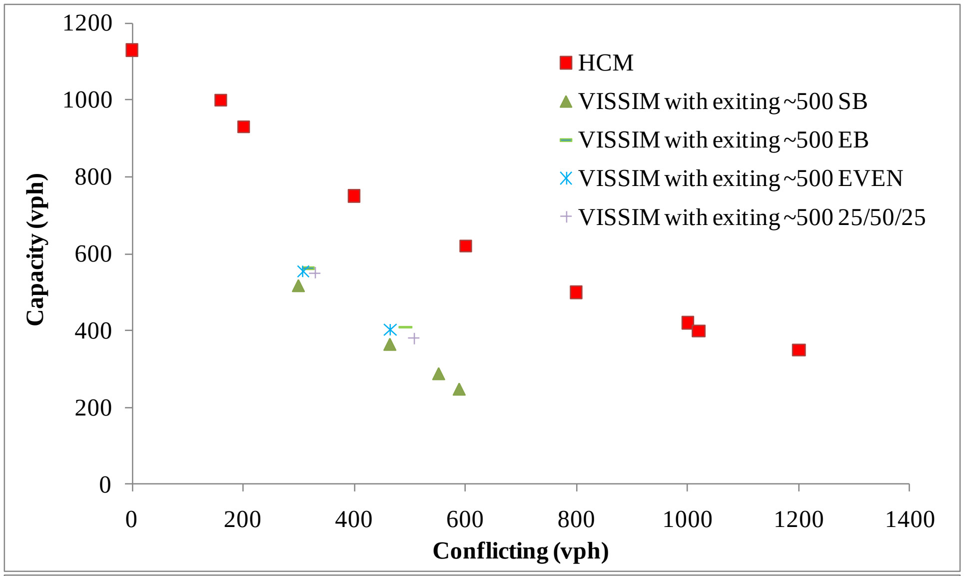


Figure 18: VISSIM results for entry lane capacity

It is also evident from Figure 19 that at the smaller San Antonio roundabout capacity varies slightly depending on the origin distribution of the conflicting traffic. For instance, capacity is at its lowest when all conflicting traffic enters from the northern leg. With the exception of the SB distribution, other distributions tend to vary little from one another. Variation seems to increase slightly as exiting traffic volume increases.



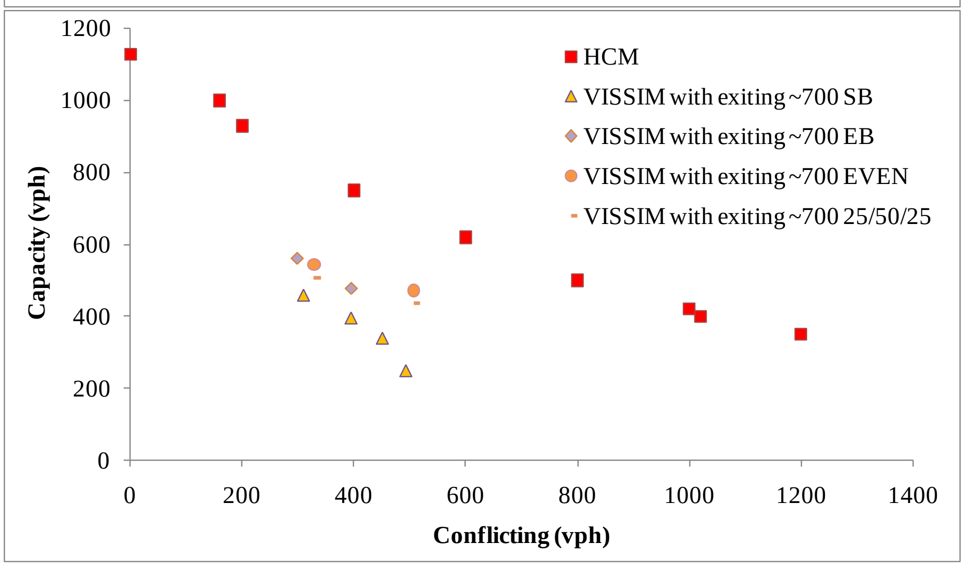


Figure 19: VISSIM entry lane capacity results with multiple distributions of the origin of traffic for ~500 vph and ~700 vph of exiting traffic

Vehicles coming from the northern entry (as in the SB scenario) traverse more of the roundabout quadrants as they exit at the leg in question and cross the path of vehicles waiting to enter. This provides vehicles with more opportunity to bunch according to the Wiedemann car following equations, which are used in VISSIM. Bunching can decrease gap sizes and therefore fewer cars may have the opportunity to enter the circulatory roadway. This could contribute to the fact that capacity is at its lowest when all traffic is coming from the northern entry.

Table 8 shows values of capacity from VISSIM for Southlake and San Antonio with approximately 500 vph conflicting traffic and approximately 700 vph exiting traffic.

Distribution of the Origin of Traffic	Roundabout	Entry Lane Capacity (vph)	Percent Difference
SB	San Antonio	395	60.8
	Southlake	740	
EB	San Antonio	476	36.4
	Southlake	688	

Table 8: Entry lane capacity with ~500 vph conflicting traffic and ~700 vph exiting traffic

The difference in capacities produced by VISSIM for the Southlake and San Antonio roundabouts could be explained by the difference in average speed of vehicles entering the roundabout and navigating the circulatory roadway. The average speeds for the Southlake and San Antonio roundabouts are approximately 20 mph and 12 mph, respectively. The speed-flow-density relationship says that flow (vehicles per hour) is a function of speed (miles/hour) and density (vehicles/mile). Therefore such a substantial difference in average speed likely contributed to the difference in entry lane flow.

The decrease in capacity could also be explained by the smaller diameter. As the inscribed circle diameter becomes smaller traffic entering from any side can sense approaching traffic more easily. At the San Antonio roundabout the diameter is small and obstructions are few so entering drivers can clearly see vehicle activity on the entire roundabout. The VISSIM model was calibrated to simulate this driver behavior. It is possible that drivers are more likely to yield to other drivers on the roundabout even though they may not necessarily conflict with their path. In the case of a larger inscribed circle diameter like Southlake, the driver cannot see activity on the entire roundabout so he considers the roundabout in terms of quadrants with the approaching fourth being the most crucial.

Results from SIDRA are shown in Figure 20. Unlike the results from VISSIM, results from SIDRA closely follow the HCM curve. This indicates that SIDRA relies heavily on equations from NHCRP 572 and HCM 2010 for calculating entry capacity even for smaller roundabouts. The speed-flow-density relationship appears to have no effect here. Capacity values from SIDRA seem to be affected minimally by the distribution of the origin of conflicting traffic unlike VISSIM as seen in Figure 21. The scenario 25/50/25 is not shown because capacity results were different from EVEN by less than 1 percent.

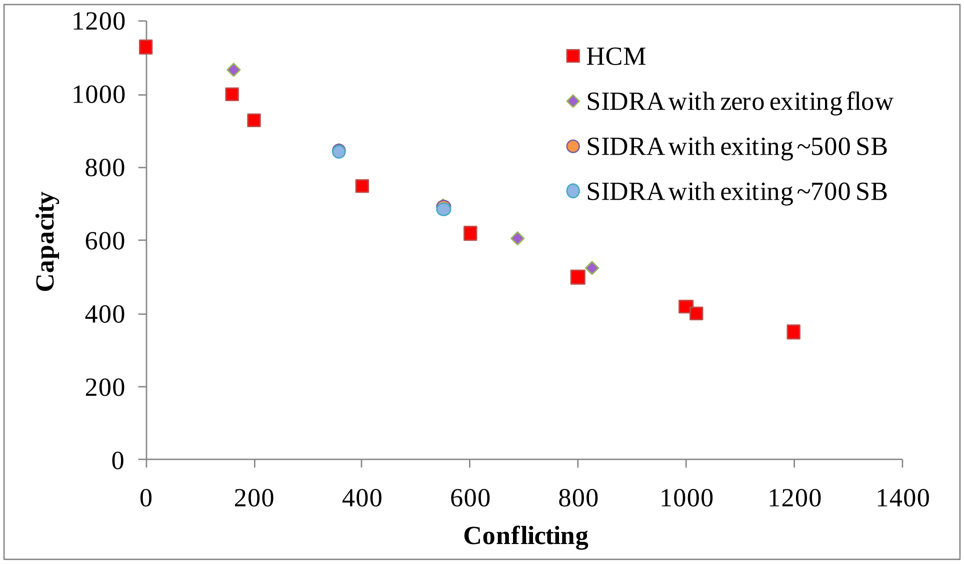


Figure 20: SIDRA results for entry lane capacity

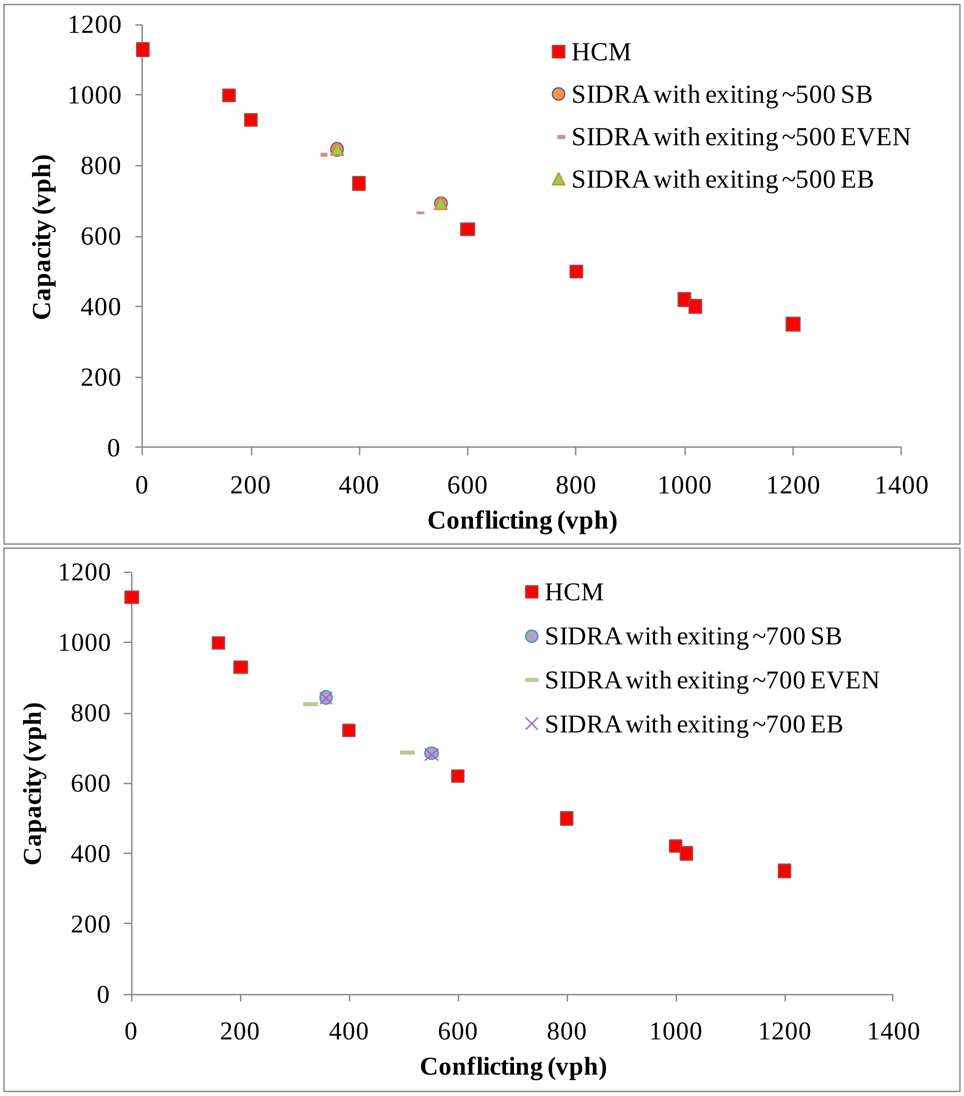


Figure 21: SIDRA entry lane capacity results with multiple distributions of the origin of traffic for ~500 vph and ~700 vph of exiting traffic

Overall, the San Antonio roundabout results from VISSIM are not comparable to SIDRA. Results from VISSIM indicate that inscribed diameter size substantially affects capacity while SIDRA does not. In some cases the difference from the HCM curve was as high as 200 vph for VISSIM results. Further research is needed to quantify the impacts of this effect and to assess the accuracy of the results from SIDRA and VISSIM for a roundabout with such a small diameter. This research indicates that SIDRA may not be accurate for a smaller roundabout that is approaching the size of a mini-roundabout and runs a great risk of overestimating entry leg capacity.

7.2 EFFECTS OF MEAN SPEED

This work investigates the difference in capacity between San Antonio and Southlake and attempts to determine the parameter that is responsible through simulation. Inscribed circle diameter and mean speed were identified as the two major differences between the roundabouts. The inscribed circle diameter of the Southlake roundabout is approximately 40 feet larger and the mean speed is 7.3 mph greater than San Antonio.

In order to gauge the effect of the inscribed circle diameter, the speed distribution of the Southlake roundabout was applied to the San Antonio roundabout and the resulting capacity values were compared to results from original San Antonio capacity values. All capacity values are with zero exiting flow. Figure 22 shows the capacity values in question.

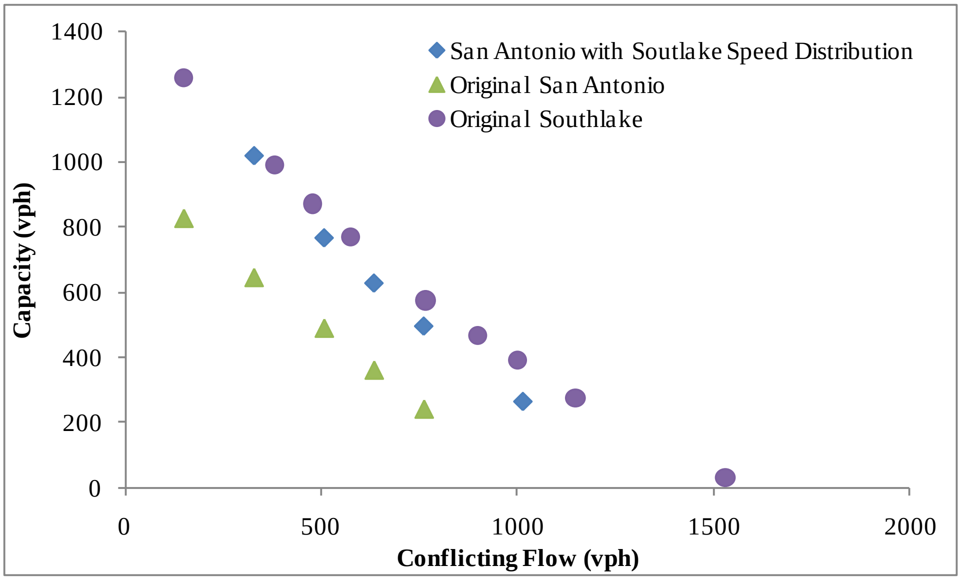


Figure 22: Comparison of capacity values for San Antonio with Southlake speed distribution, San Antonio with its original speed distribution, and Southlake with its original speed distribution.

By changing the speed distribution, the capacity values for the San Antonio roundabout are much closer to the capacity values for the Southlake roundabout despite the remaining difference in inscribed circle diameter. This suggests that the difference between the two roundabouts' speed distributions is primarily responsible for difference in entry lane capacity.

The VISSIM model for the Southlake roundabout was used to explore the effect of the mean speed of a roundabout on entry lane capacity further. The Southlake speed distribution was used as the base speed distribution. This base distribution was modified into four additional speed distributions by adding and subtracting a specified value from each point on the curve. For example, 5 mph was subtracted from each point on the original Southlake speed distribution to create a new speed distribution with a mean speed of 13.9 mph. Each distribution is represented with its resulting mean speed throughout this discussion. The distributions include 13.9 mph, 18.9 mph (the original distribution), 23.9 mph, 28.9 mph, and 38.9 mph. Figure 23 shows the capacity curve for the five speed distributions.

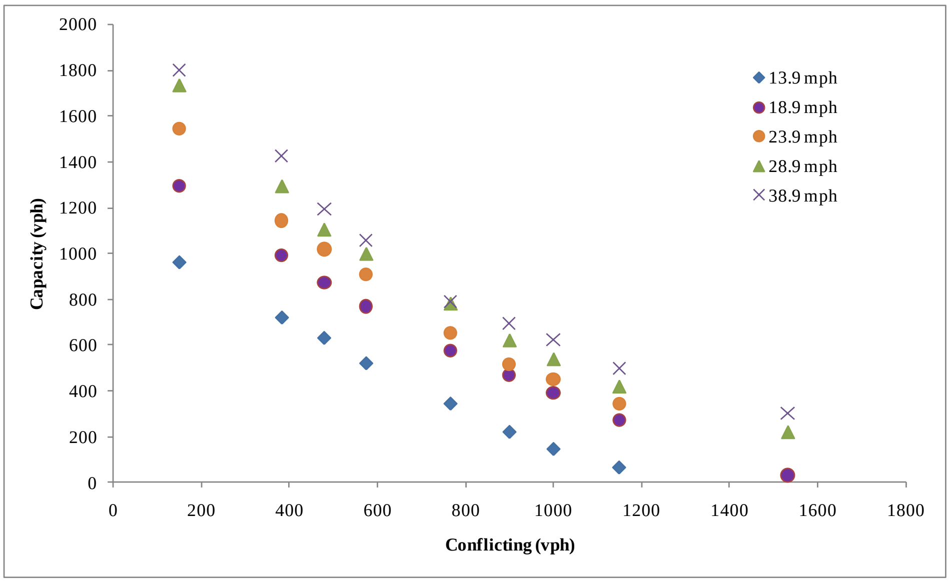


Figure 23: Capacity curve for varying speed distributions

At mean speeds of 18.9 mph and below, the data appears to be linear but beyond this range the curves are more exponential. Using these curves, equations were developed that may be useful in determining capacity depending on expected speed and conflicting traffic:

When mean speed is between 13.9 mph and 23.9 mph:

$$c = 666.641 - 1.045 v_c + 36.963 s$$

When mean speed is above 23.9 mph:

$$c = (1699.086 + 14.334 s) e^{-0.001 v_c}$$

where,

c = entry lane capacity (veh/hr)

s = speed (mi/hr)

v_c = conflicting traffic (veh/hr)

These equations are meant to act as a planning tool to give the user a general idea of the entry lane capacity they can expect given the expected mean speed of the roundabout and volume of conflicting traffic.

Chapter 8 – Summary of Findings

The answer to one of the main objectives of this work – can the Highway Capacity Manual be used to predict capacity at Texas roundabouts? – the answer appears to be "it depends." Using VISSIM results as the baseline, the HCM provided reasonable approximations when (1) the roundabout diameter is "typical" for a single-lane roundabout (here, "typical" was 130 feet), (2) the conflicting flow rate is "low" or "medium" (here, less than ~ 760 vph) and (3) the exiting flow rate is "medium" (~ 760 vph). These conditions may appear strict, but it is likely that most roundabouts will experience conditions in these ranges. Further study is needed to provide guidelines on how the HCM results can be adjusted to provide better capacity estimates. However, the trends discussed in the bullet points below will provide a starting point to any potential adjustments.

Another objective of this work was to evaluate SIDRA INTERSECTION as software for evaluating roundabouts in Texas. SIDRA capacity results were shown to follow the HCM curve more closely than the results from VISSIM and in most cases SIDRA provides results that are between those of HCM and VISSIM. For this reason, this work recommends the use of SIDRA when (1) traffic analysis is needed that exceeds the capabilities of the planning method located in NCHRP 672 (2) the software is available and (3) using VISSIM is too time-consuming. Unlike VISSIM, which is a microsimulation model, SIDRA is a much simpler analytical tool. As described in the "Software and Procedures" section of this document, roundabout analysis is made very easy in SIDRA through the use of templates and it allows for some calibration based on local conditions, unlike using the HCM curve. While VISSIM gives the most behaviorally consistent results, building a model can be time-consuming and is unlikely to be used in practice unless the roundabout design is especially complex and does not fit any of the SIDRA templates.

A summary of results is below.

Southlake Roundabout (130-foot diameter, 20mph average entering speed)

Comparing HCM Capacity Curve Results to VISSIM Results

- When exiting flow is low and conflicting flow is below approximately 800 vph the HCM curve underestimates capacity and then overestimates capacity beyond this threshold.
- If exiting traffic is ~760 vph, and conflicting traffic is less than 600vph the HCM curve predicts accurately.
- If exiting traffic is increased to ~1100 vph the HCM curve overestimates capacity for all conflicting flows studied (~300 to ~720vph).
- As exiting traffic volumes increase, the effect of the distribution of entering traffic among intersection legs increases. In fact, distribution of traffic among roundabout entry points (origin of traffic) does not affect capacity when exiting traffic is ~760 vph, however, when exiting traffic increases to ~1100 vph, the distribution has a greater effect on approach leg capacity. The differences in capacity are small, but approach capacity is lowest when all conflicting and exiting traffic comes from the

opposite side of the roundabout and is highest when this traffic is evenly distributed across the approach legs.

Comparing HCM Capacity Curve Results to SIDRA Results

- Compared to SIDRA, the HCM curve underestimates capacity when exiting traffic is ~760 vph or less but not when exiting traffic is increased to ~1100 vph
- Capacity estimates from SIDRA are variable depending on the distribution of the origin of traffic if exiting flow is ~760 vph. However, there is less variation when exiting traffic is increased to ~1100 vph. This is opposite to what was observed through VISSIM capacity results.
- Overall SIDRA values are comparable to HCM.

San Antonio (90-foot diameter, 12mph average entering speed)

Comparing the three capacity estimation methods:

- Compared to VISSIM results, the HCM curve highly overestimates capacity for all scenarios tested.
- VISSIM capacity estimates seem to be affected by the distribution of entering traffic among roundabout legs. If exiting traffic is ~760 vph, the distribution of the origin of traffic has a slight effect on VISSIM capacity results and this effect increases when exiting traffic volume increases.
- Overall SIDRA values are comparable to HCM.

- Exiting traffic volume and distribution of origin of traffic have little effect on SIDRA entry lane capacity.

Mean Speed

The mean speed of a roundabout appears to have an effect on roundabout capacity. A linear relationship between traffic speed and capacity was observed when mean speed is between 13.9 mph and 23.9 mph. The relationship becomes exponential as mean speed exceeds 23.9 mph. Equations are presented to predict entry-lane capacity based on expected mean speed and conflicting traffic. More research is needed to further explore the validity and usefulness of these equations.

References

Akcelik & Associates Pty Ltd. (2009) SIDRA INTERSECTION User Guide (For Version 4). Web.

Akcelik, R. An Assessment of the Highway Capacity Manual 2010 Roundabout Capacity Model. in Transportation Research Board International Roundabout Conference, Carmel, Indiana, 2010.

Akcelik, R. A Roundabout Case Study Comparing Estimates from Alternative Analytical Models. in 2nd Urban Street Symposium, Anahiem, California, 2003.

Akcelik, R. Roundabouts with unbalanced flow patterns. in Compendium of Technical Papers, Institute of Transportation Engineers 2004 Annual Meeting Exhibition, Lake Buena Vista, Florida, 2004.

Bared, J., and P.K. Edara. Simulated Capacity of Roundabouts and Impact of Roundabout Within a Progressed Signalized Road. in Transportation Research Board National Roundabout Conference, Vail, Colorado, 2005.

Committee, T. E. Critical Issues in Transportation: 2009 Update. Transportation Research Board of the National Academies, Washington, D.C., 2009.

Gagnon, C., A.W. Sadek, A. Touchette, and M. Smith. Calibration Potential of Common Analytical and Micro-simulation Roundabout Models: A New England Case Study. Transportation Research Record: Journal of the Transportation Research Board, Vol. 2071, 2008, pp. 77-86.

Gettman, D., and L. Head. Surrogate Safety Measures From Traffic Simulation Models. Federal Highway Administration , Final Report FHWA-RD-03-050, 2003.

Hagring, O. Derivation of Capacity Equation for Roundabout Entry with Mixed Circulating and Exiting Flows. Transportation Research Record: Journal of the Transportation Research Board, Vol. 1776, 2001, pp. 91-99.

Kinzel, C.S., and M.T. Trueblood. The Effects of Operational Parameters in the Simulation of Roundabouts. 2004. http://www.kutc.ku.edu/pdffiles/roundaboutsim.pdf.

Krogscheepers, J.C., and C.S. Roebuck. Unbalanced Traffic Volumes at Roundabouts. in Fourth International Symposium on Highway Capacity, Washington, D.C., 2000, pp. 446-458.

Mereszczak, Y., M. Dixon, M. Kyte, L. Rodergerdts, and M. Blogg. Including Exiting Vehicles in Capacity Estimation at Single-Lane U.S. Roundabouts. Transportation Research Record: Journal of Transportation , Vol. 1989, 2006, pp. 23-30.

Oketch, T., M. Delsey, and D. Robertson. Evaluation of Performance of Modern Roundabouts Using Paramics Microsimulaion Model. in Transportation Association of Canada, Quebec City, Quebec, 2004.

Rodergerdts, L., J. Bansen, C. Tiesler, J. Knudsen, E. Myers, M. Johnson, M. Moule, B. Persaud, C. Lyon, S. Hallmark, H. Isebrands, R. Crown, B. Guichet, and A. O'Brien. Roundabouts: An Informational Guide Second Edition. Transportation Research Record Nation Academies of Science, Washington, D.C., National Cooperative Highway Research Program Report 672, 2010.

Rodergerdts, L., M. Blogg, E. Wemple, E. Myers, M. Kyte, M. Dixon, G. List, A. Flannery, R. Troutbeck, W. Brilon, N. Wu, B. Persaud, C. Lyon, D. Harkey, and D. Carter. Roundabouts in the United States. Transportation Research Record National Academies of Science, Washington, D.C., National Cooperative Highway Research Program Report 572, 2007.

Stanek, D., and R.T. Milam. High-Capacity Roundabout Intersection Analysis. in Transportation Research Board National Roundabout Conference, Vail, Colorado, 2005.

Transportation Research Board. Highway Capacity Manual 2010. Transportation Research Board of the National Academies, Washington, D.C., 2010.

Troutbeck, R.J. Does Gap Acceptance Theory Adequately Predict the Capacity of a Roundabout. in ARRB Conference, Vol. 12, Hobart, Tasmania, 1985, pp. 62-75.

Troutbeck, R. J. Traffic Interactions at Roundabouts. Proc., 15th ARRB

Conference, Vol. 15, Part 5, 1990

Verkehr, P. T. (2007) VISSIM 5.00 User Manual. Web.

Wei, T., and J.L.. S.H.R. Grenard. Developing Capacity Models for Local Roundabouts: A Streamlined Process. in Transportation Research Board of the National Academies, Washington, D.C., 2011.

Vita

Alison Fayre Mills was born July 8, 1986 in northern Virginia. She is the daughter of Arthur and Leila Mills. She has two brother and three sisters. After graduating from Allen High School in Allen, TX in 2004 she attended Collin County Community College for a year before enrolling at the University of Texas at Austin in Austin, TX in August 2005. She received a Bachelor of Science in Civil Engineering in May 2009. In August 2009 she entered the Graduate School at the University of Texas at Austin. After receiving a Master of Science in Engineering she plans to work in the field of Transportation Engineering.

Permanent email address: ali.fayre@gmail.com

This thesis was typed by Alison Fayre Mills.